

CBO TESTIMONY

Statement of
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Director

Costs of Reprocessing Versus Directly Disposing of Spent Nuclear Fuel

before the
Committee on Energy and Natural Resources
United States Senate

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Mr. Chairman, Senator Domenici, and Members of the Committee, thank you for the invitation to discuss the Congressional Budget Office's (CBO's) analysis of the costs of two alternatives for the use and disposal of nuclear fuel. For the past 50 years, the nuclear waste produced at reactors across the United States has largely been stored at the reactor sites. That practice, however, has been deemed untenable for the long run.

CBO's analysis compares the cost of two fuel-cycle alternatives for the current generation of thermal reactors.¹ One alternative is the "direct disposal" approach stipulated by current law, which involves using nuclear fuel once, cooling it on site at the reactor, and then disposing of the waste in a long-term repository. The second alternative is the "reprocessing" approach, in which spent nuclear fuel is cooled on site and then reprocessed for one additional use in a reactor, and the wastes from reprocessing are stored in a long-term repository.

My testimony makes the following key points:

- The cost of directly disposing of spent nuclear fuel is less than the cost of reprocessing it. That basic result holds across a wide range of plausible assumptions, but the magnitude of the cost difference between the two alternatives varies significantly among different analyses.
- Two studies illustrate the range of estimates of the cost difference between reprocessing and direct disposal. A study by the Boston Consulting Group (BCG) estimated that reprocessing spent nuclear fuel would cost about \$550 per kilogram—about 6 percent more than direct disposal. Another study, by a group of researchers affiliated with Harvard University's Kennedy School of Government, suggests that reprocessing would cost about \$1,300 per kilogram—or more than twice as much as direct disposal.
- From its analysis of those and other studies, CBO concludes that for the roughly 2,200 metric tons of spent fuel produced each year in the United States, the reprocessing alternative would be likely to cost \$5 billion to \$11 billion more in present-value terms than the direct-disposal alternative for 40 years' worth of waste handling. (Present-value figures convert a stream of future costs into an equivalent lump sum today.) The higher cost for reprocessing is equivalent to a 25 percent to 50 percent increase over the cost of direct disposal.

1. The Global Nuclear Energy Partnership (GNEP) envisions that the nuclear power industry will use a new generation of reactors—called advanced burner reactors—and an advanced fuel cycle that could substantially reduce the amount of nuclear waste requiring long-term storage. In addition, the advanced fuel cycle would not separate out plutonium from that waste in a form that can be used to produce nuclear weapons. Nevertheless, comparing the costs of alternative fuel cycles for current thermal reactors may provide useful information for making policy decisions about the design and funding of the GNEP program.

- Major sources of uncertainty in such estimates include how much it would cost to build and operate a reprocessing facility, how long the facility would last, whether economies of scale would occur if such a facility was expanded to reprocess existing as well as future spent fuel, and the market value of reprocessed fuel.
- Policymakers evaluating the reprocessing and direct-disposal options may be concerned not only about cost but also about such potentially important issues as the impact of the alternatives on the threat of nuclear proliferation and the need for long-term storage space for spent fuel. Those issues are largely beyond the scope of CBO’s analysis.

Background on Nuclear Fuel-Cycle Alternatives

As of 2006, 104 nuclear reactors were operating in the United States, with a collective generating capacity of about 100 gigawatts of electricity. Those reactors account for nearly 20 percent of the electricity produced in this country.²

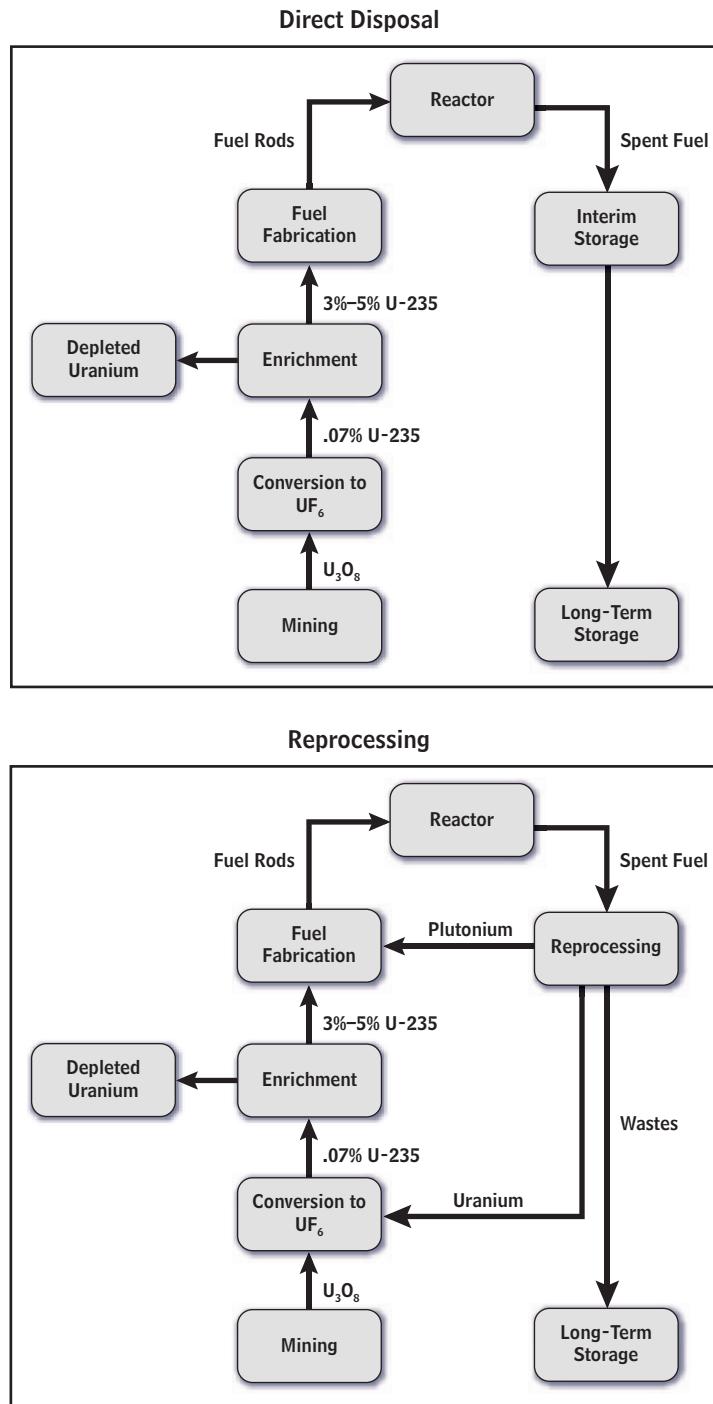
All of the commercial nuclear power plants in the United States generate electricity by relying on the uranium 235 isotope to sustain a nuclear reaction. Uranium 235 is relatively scarce and typically makes up less than 1 percent of mined uranium ore. (The bulk of that ore consists of uranium 238, which cannot be used directly to sustain a nuclear fission chain reaction.) For a sustained reaction to occur, the uranium must be enriched—that is, the proportion of uranium 235 must be increased, generally to between 3 percent and 5 percent of the fuel used for civilian reactors.

After approximately four years in a reactor, too little uranium 235 remains in the fuel to generate electricity. The spent fuel can be handled in one of two ways: Under direct disposal, it is placed in interim storage for cooling, with the goal of eventually storing it in a stable geologic formation over the long term. Under reprocessing (which is done in a few countries but not the United States), a reprocessing facility recovers the useful components of the spent fuel—uranium and certain forms of plutonium—and returns them to the fuel cycle, where they are combined with newly mined uranium to produce more reactor fuel (see Figure 1). Any waste remaining from the spent nuclear fuel after the uranium and plutonium are removed is intended to be stored in a long-term repository. Thus, under either option, some form of a long-term storage facility is necessary.

No long-term repository for storing commercial nuclear waste is currently operating anywhere in the world. The Department of Energy (DOE) is planning to build and operate such a repository at Yucca Mountain in Nevada. That facility, originally scheduled to open in 1998, is now intended to start operating in 2017,

2. Department of Energy, Energy Information Administration, *Annual Energy Review 2006* (June 2007), Table 8.2a, available at www.eia.doe.gov/emeu/aer/pdf/pages/sec8_8.pdf.

Figure 1.
Nuclear Fuel Cycles



Source: Congressional Budget Office based on Ian Hore-Lacy, *Nuclear Energy in the 21st Century* (London: World Nuclear University Press, 2006).

Note: U_3O_8 = uranium oxide concentrate; UF_6 = uranium hexafluoride; U-235 = uranium 235.

although a later opening date—2020 or 2021—is more likely.³ That date would be nearly 40 years after lawmakers directed DOE to begin studying potential sites for a deep underground repository for spent nuclear fuel.⁴

With such delays, the accumulated stock of nuclear waste is expected to exceed Yucca Mountain’s mandated capacity before the facility begins accepting waste for storage. One approach to that problem is to expand the repository’s capacity, either physically or by lifting the mandated limit on how much waste Yucca Mountain can accept (an option that many observers contend could be done without compromising safety). Another approach is to reprocess spent nuclear fuel for reuse in reactors. That option has the potential to increase the effective capacity of the repository by allowing more spent fuel to be stored in a given amount of space.

The main factor that determines the overall storage capacity of a long-term repository is the heat content of nuclear waste, not its volume. The waste that results from reprocessing spent fuel from thermal reactors has a lower heat content (after a period of cooling) than the spent fuel does. Thus, it can be stored more densely.⁵ The extent of that densification directly affects the relative costs of direct disposal and reprocessing. However, unlike waste from the reprocessing process, spent fuel that has been reprocessed and used again has a higher heat content than spent fuel that has been used only once. Storing that previously recycled spent fuel in the long-term repository immediately would eliminate all of the densification benefits of reprocessing. Consequently, for reprocessing to reduce the need for—and cost requirements of—long-term storage capacity, previously recycled spent fuel would have to be allowed to accumulate at some location outside the repository until it cooled enough for long-term storage.

Besides potentially lowering long-term disposal costs, reprocessing spent nuclear fuel has the advantage of reducing expenditures for freshly mined and enriched uranium. In effect, recovering unused uranium from spent fuel extends the life of unmined uranium resources. Furthermore, recovered plutonium is not subject to many of the fuel-preparation costs that uranium must undergo (see Figure 1). That potential for front-end savings was especially appealing when the U.S. commercial nuclear program began in the 1950s. It became less pronounced by the 1960s,

3. Statement of Edward F. Sproat, Director, Office of Civilian Radioactive Waste Management, at the 178th meeting of the Nuclear Regulatory Commission’s Advisory Committee on Nuclear Waste, April 10, 2007, available at www.nrc.gov/reading-rm/doc-collections/acnw/tr/2007/nw041007.pdf
4. As originally enacted, the Nuclear Waste Policy Act of 1982 called for studies of three potential sites for long-term geologic repositories. Sections 5011 and 5012 of the Nuclear Waste Policy Amendments Act of 1987 effectively cancelled any investigation into sites other than the one at Yucca Mountain.
5. The “densification factor” describes that relationship; for example, a densification factor of two indicates that twice as much waste from reprocessing can be stored at the same total cost (in other words, that the unit cost of storage is half as much).

as uranium prices declined from the levels of prior decades and uranium preparation techniques matured. Today, spot prices for uranium are at historical highs (adjusted for inflation), but high prices would have to persist for decades to make reprocessing more economically viable to any material extent.

Reprocessing and direct disposal differ not only in potential costs but also in possible risks for the proliferation of nuclear weapons. Spent nuclear fuel itself poses little risk of proliferation because the plutonium it contains is mixed with highly radioactive elements and can be recovered only in dedicated reprocessing facilities.⁶ But the most widely used method of reprocessing—called plutonium and uranium recovery by extraction, or PUREX—yields pure plutonium, which has relatively low radioactivity and can be handled directly. Thus, the PUREX method recovers plutonium in a form that poses risks for theft and proliferation. Other reprocessing methods being considered by policymakers try to reduce those risks by not separating out pure plutonium from spent fuel.

Reprocessing Facilities

The United States has never yet reprocessed spent nuclear fuel from commercial reactors. Three reprocessing plants were built that were intended for commercial use, but only one—a plant in West Valley, New York, that opened in 1966—achieved any level of operation. The need for costly upgrades caused it to close in 1976, having handled only spent fuel from national defense facilities.

Today, five nations—France, the United Kingdom, Japan, Russia, and India—have or are developing reprocessing facilities. The world's largest reprocessing plant is located in La Hague, France, and has a gross capacity of 1,700 metric tons per year. The United Kingdom has two reprocessing centers at its Sellafield Nuclear Site: a 900-metric-ton thermal oxide reprocessing plant (THORP) and a facility that specializes in reprocessing waste for two specific British nuclear facilities (Oldbury and Wylfa, both of which are expected to cease operations by 2010). Another reprocessing facility has been under construction in Rokkasho, Japan, since the late 1980s. The start of commercial operations there has been delayed several times but is now expected to occur later this year.

Thermal Reactors Versus Fast-Neutron Reactors

CBO's analysis compares the cost of reprocessing nuclear fuel for thermal reactors—the type of commercial reactor used now in the United States—with the cost of using uranium fuel a single time and then putting all of it in a geologic repository. However, some current policy initiatives, such as the Global Nuclear Energy Partnership, focus on another type of reactor: an advanced burner reactor, which is a type of fast-neutron reactor. Whereas thermal reactors rely on less energetic, or modulated, neutrons to sustain a nuclear chain reaction, fast-neutron reactors rely

6. Steve Fetter and Frank N. von Hippel, “Is U.S. Reprocessing Worth the Risk?” *Arms Control Today* (September 2005), available at www.armscontrol.org/act/2005_09/Fetter-VonHippel.asp.

on unmodulated (and hence more energetic) neutrons for a reaction. Fast-neutron reactors use plutonium as a fuel source rather than uranium because plutonium maintains a reaction with unmodulated neutrons more readily than commercial-grade enriched uranium does.

Fast-neutron reactors offer several advantages. They can convert plentiful uranium 238 (which is not usable for nuclear chain reactions) into plutonium in such a way as to produce (or breed) more plutonium than the reactor itself uses. In that way, a fast-neutron breeder reactor can extend uranium resources by accessing 60 to 100 times more of the energy content of uranium than thermal reactors can.⁷ In addition, fast-neutron reactors generate less spent fuel than thermal reactors do.

Besides uranium and plutonium, spent nuclear fuel includes two other types of waste: fission products and minor actinides. Minor actinides decay less rapidly than fission products do. Because the capacity of a geologic repository depends to a significant degree on the long-term radioactivity of waste, it is greatly influenced by the amount of minor actinides present in spent fuel. Advanced burner reactors can potentially burn all of the actinides contained in nuclear fuel, so waste from those reactors requires less geologic storage space than does either spent nuclear fuel from thermal reactors or the waste from reprocessing thermal reactors' spent fuel.

Whereas fuel reprocessing is merely an option with thermal reactors (to extend uranium resources or to potentially expand long-term storage capacity), it is an integral part of the fuel cycle for advanced burner reactors. The fuel needed to power advanced burner reactors can be collected by reprocessing spent fuel from thermal reactors or from burner reactors. Furthermore, if burner reactors are used to reduce thermal-reactor waste, spent nuclear fuel must be reprocessed.

This testimony does not consider reprocessing in the context of fast-neutron reactors, for three reasons. First, no commercial fast-neutron reactors exist in the United States and none are planned. Second, the 60-year-old PUREX process is essentially the only reprocessing method used for thermal reactors, and given its long history, the cost of PUREX is less speculative than the costs of more-recent reprocessing technologies that are being considered for fast-neutron reactors. Third, reprocessing fuel for advanced burner reactors would probably require reprocessing nuclear waste from thermal reactors as a first step in order to create the fuel for the burner reactors and to manage any existing thermal-reactor waste. Thus, reprocessing thermal-reactor waste can be thought of as a transitional element to a burner-reactor program.

7. Uranium Information Centre, *Fast Neutron Reactors*, Briefing Paper No. 98 (Melbourne, Australia: Australia Uranium Association, June 2006), available at www.uic.com.au/nip98.htm.

Cost Comparisons for Direct Disposal and Reprocessing

As noted, reprocessing nuclear fuel could have two main economic advantages over direct disposal. It could reduce spending on newly produced uranium fuel and extend the useful life of uranium resources. In addition, it could save money on long-term storage by reducing the size of the repository necessary to handle spent nuclear fuel or by delaying the need to expand such a facility in the future.

With current reactor technology, reprocessing also has economic disadvantages. First, it requires building dedicated facilities to recover the useful components of spent nuclear fuel and then to combine them into a form usable in a nuclear reactor. Second, previously recycled spent fuel also needs some form of long-term storage. As explained above, given its radioactivity, that spent fuel could eliminate all of the storage-related cost savings from reprocessing if it was placed in a long-term geologic repository.

To quantify the relative costs of reprocessing and direct disposal, CBO's analysis focuses on the back-end costs of handling nuclear fuel after it is discharged from a reactor. In the case of reprocessing, those back-end costs include the costs of reprocessing services (both recovering uranium and plutonium and fabricating them into usable nuclear fuel), transportation, and long-term disposal of wastes, partially offset by "fuel credits," which various models use to reflect the value of the reprocessed fuel (in the form of savings on the front-end costs of newly purchased fuel). In the case of direct disposal, back-end costs include costs for interim storage to cool the spent fuel, transportation, and long-term disposal.

CBO reviewed a number of recent studies that shed light on the costs of nuclear fuel-cycle alternatives, among them studies by the National Academy of Sciences, the Massachusetts Institute of Technology, and the Idaho National Laboratory. However, CBO's analysis focused on two studies in particular: a 2006 report by the Boston Consulting Group (BCG) and a 2003 report by researchers at Harvard University's Kennedy School of Government.⁸ Those two studies are the only recent analyses available that investigate the costs of all facets of both reprocessing and direct disposal (including transportation, interim storage, and credits for recycled fuel). Other studies consider only the costs of reprocessing or do not examine the various components of total costs. In addition, the two studies' estimates of the cost of reprocessing services—one of the largest cost elements—bound the range of estimates provided in, or implied by, the other studies. The Kennedy study's estimate of the cost of reprocessing services is about twice the

8. Boston Consulting Group, *Economic Assessment of Used Nuclear Fuel Management in the United States* (study prepared for AREVA Inc., July 2006); and Matthew Bunn and others, *The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel* (Cambridge, Mass.: Belfer Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University, December 2003).

size of the BCG study's estimate. Other studies that CBO examined had cost estimates for reprocessing services that fell within the range defined by those two reports.

Evaluating the Boston Consulting Group and Kennedy Studies on a Common Ground: Approach and Results

The BCG study concludes that reprocessing spent fuel costs about \$30 more per kilogram than direct disposal. To directly compare that estimate with the results of the Kennedy study, CBO modified the Kennedy study to reflect a similar initial framework as in the BCG study. In that framework, the Kennedy study implies that reprocessing costs about \$700 more per kilogram than direct disposal. Given the volume of waste expected to be generated over the next 50 years, those baseline values suggest that the present-value cost of reprocessing exceeds that of direct disposal by about \$2 billion for the BCG study and by about \$26 billion for the Kennedy study, as modified by CBO. (Present-value calculations use a discounted cost framework, which describes the amount of funds that would be necessary in 2007 to pay all of the costs of a waste-management option over 50 years.)

Several differing assumptions account for much of the gap between those two present-value estimates. Such assumptions include the time horizon over which a reprocessing plant operates, its financing costs, and the relationship between its yearly operating costs and total capacity costs; the cost of a long-term repository; and the degree to which waste from reprocessing can be stored less expensively than spent nuclear fuel in that repository. Changes to any of those assumptions will affect the relative costs of the two waste-handling alternatives. To control for those differences, CBO's analysis imposed a common set of cost assumptions on the estimates from the BSG study and from the modified Kennedy study. In particular, CBO assumed the following:

- A plant lifetime of 40 years, the midpoint between the 50-year figure used in the BCG study and the 30-year lifetime assumed in the Kennedy School study.
- A discount rate of 3.5 percent, which lies between the rates used in the two studies.
- Plant operating costs that equal 6 percent of the plant's capital costs, a rule of thumb adopted in an analysis by the Organisation for Economic Co-operation and Development. That figure lies between the 4.5 percent ratio implied by the BCG study and the 7.5 percent ratio implied by the Kennedy study.
- Repository costs of \$1,036 per kilogram of heavy metal stored in the repository, an estimate that CBO developed using cost data from DOE. That cost exceeds both the \$736 per kilogram figure in the BCG study and the \$868 per kilogram estimate in the Kennedy study.

- A densification factor of 2.5 applied to repository capacity, based on a study by the Idaho National Laboratory. That figure is between the densification factor of 4 used in the BCG study and the factor of 2 implied by the Kennedy study.

As those common assumptions are successively applied, the span of the two present-value estimates narrows from a range of \$2 billion to \$26 billion to a range of \$5 billion to \$11 billion (see Figure 2).

Most of that remaining gap is attributable to the two studies' different assumptions about the costs of building and operating a reprocessing plant. The BCG study implies an estimated construction cost of about \$17 billion for a plant with a capacity of 2,500 metric tons per year. A meaningful comparable estimate can not be derived from the Kennedy study because that analysis does not differentiate between capital and operating costs. The likelihood that a newly built U.S. plant would match either studies' cost assumptions is difficult to judge; the historical record provides scant evidence about the overall cost of a reprocessing facility and its component parts. Not only are there few large-scale commercial reprocessing plants, but only limited information is available about their construction and operating costs.

Neither the 900-metric-ton THORP facility in the United Kingdom nor the 1,700-metric-ton La Hague facility in France has enough capacity to handle the 2,200 metric tons of nuclear waste generated in the United States each year—the amount considered in this analysis. Thus, a facility larger than any past or current example would be necessary if a single reprocessing plant was to handle the United States' entire annual output of spent nuclear fuel.

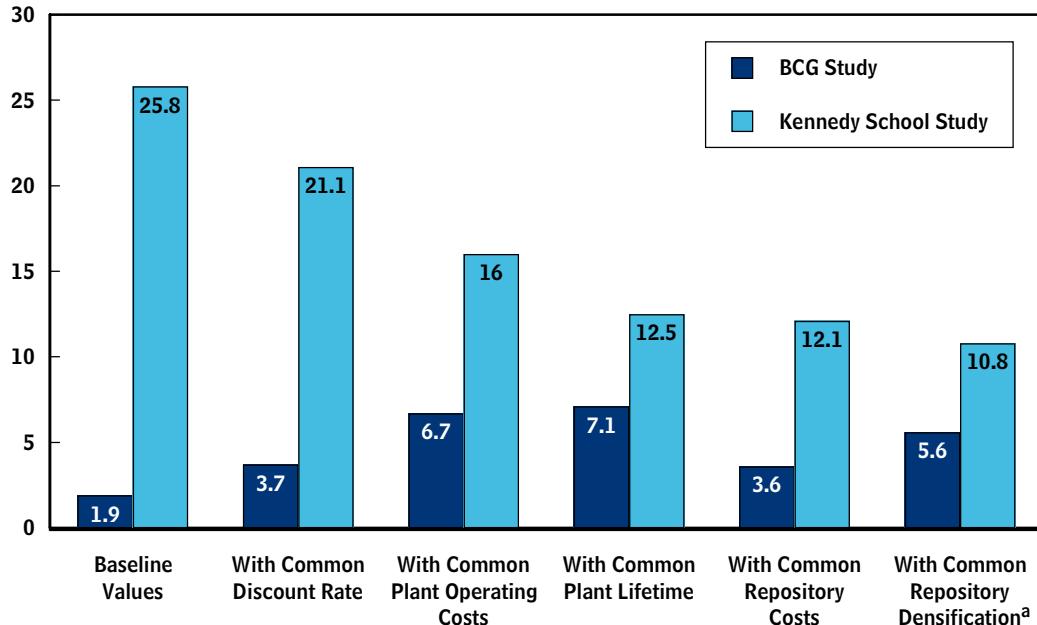
A larger facility would be more costly than existing plants, although to what degree is unknown. The limited information available suggests that building the THORP plant cost around \$6.3 billion (in 2007 dollars). The BCG study indicates that the construction cost of the La Hague facility was around \$18 billion (though, unlike the THORP estimate, this total includes a fabrication facility for recycled fuel, which increases the overall cost). The nearly complete 800-metric-ton Rokkasho facility in Japan will reportedly cost about \$21 billion, but a portion of that cost is attributable to specifics of the plant's location that would not necessarily apply to a U.S. facility. Given the lack of numerous commercial reprocessing facilities to use as examples, though, it is difficult to know how much geographic location, economies of scale, and regulatory environment matter for the cost of a reprocessing plant.

All of the costs for reprocessing services included in this analysis assume that the plant will operate near capacity for its entire life. The historical record, however, suggests that such an assumption may be optimistic and therefore the unit cost of reprocessing may be higher than described here. Neither THORP nor La Hague has operated close to full capacity for a substantial period. THORP has been closed for more than two years after experiencing a radioactive leak. Before that,

Figure 2.

Discounted Cost Differences Between Reprocessing and Direct Disposal

(Present-value difference, in billions of 2007 dollars)



Source: Congressional Budget Office based on Boston Consulting Group (BCG), *Economic Assessment of Used Nuclear Fuel Management in the United States* (study prepared for AREVA Inc., July 2006); and Matthew Bunn and others, *The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel* (Cambridge, Mass.: Belfer Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University, December 2003).

Note: The numbers shown here represent the extent to which the 50-year costs of reprocessing spent nuclear fuel exceed the 50-year costs of direct disposal on a present-value basis. (Present-value figures convert a stream of future costs into an equivalent lump sum today.) The first set of bars shows the values implied by the BCG and Kennedy School studies under their different assumptions. The successive sets of bars show the cumulative effects of applying common assumptions to the two baseline estimates. The common assumptions that CBO used for this analysis are described in detail in the text.

a. Densification refers to the extent to which waste from reprocessing can be stored more densely in a long-term repository than unprocessed spent fuel.

the plant operated at about 60 percent of capacity over its first 11 years. Although La Hague has not had the technical problems of the THORP facility, it too is operating well below full capacity: at approximately 65 percent, according to recent estimates. Operating at less than full capacity either limits the amount of spent fuel that can be handled for the same total cost or requires more outlays to reprocess the same amount of fuel.

Another factor that could increase the estimated cost of reprocessing relative to direct disposal is the discount rate used in present-value calculations. (The discount rate is the interest rate used to compute the present value of future costs.) The rate assumed in this analysis is higher than that available under a risk-free government program. But the rate that would apply for a fully private venture would be much higher, resulting in a larger cost difference between reprocessing and direct disposal.

The relative cost of reprocessing is also affected by the market value of recycled fuel. As noted above, the fuel credits used in this analysis reflect front-end savings from using recycled fuel rather than newly mined uranium. If the costs of uranium mining and fuel preparation increased, and if recycled fuel proved to be a good substitute for newly mined uranium in nuclear reactors, higher fuel credits could offset the cost of reprocessing to a greater extent. Although uranium prices are currently high by historical standards, it is not certain whether high prices will continue in the future or whether current prices will encourage additional uranium development that may lower prices. Furthermore, modifying a nuclear reactor to use recycled fuel entails some costs, which would offset a portion of the potential fuel credits from reprocessing.

Sensitivity to Varying Assumptions

Although the size of the cost difference between reprocessing and direct disposal depends on inputs to specific models, the conclusion that reprocessing is more expensive than direct disposal generally applies under various assumptions. CBO tested the sensitivity of the results to changes in some of the key parameters of this analysis:

- An increase of 1 percentage point in the discount rate increases the difference in present-value costs between reprocessing and direct disposal by between \$3 billion and \$4 billion.
- A reduction in the assumed operating costs of a reprocessing plant narrows the cost gap between reprocessing and direct disposal. For example, decreasing the ratio of a plant's operating costs to its capital costs by 1 percentage point reduces the present-value cost differential by between \$2 billion and \$3 billion. However, operating costs would have to be significantly lower—at least 80 percent lower—for reprocessing to cost the same as or less than direct disposal.

- A change in the assumed operating lifetime of a reprocessing facility has no material impact on the cost differential for the two waste-handling alternatives.
- A rise in the cost of the long-term storage repository reduces the difference between the costs of reprocessing and direct disposal. That cost would have to increase to a very great extent, however, for direct disposal to cost as much as reprocessing. Even then, if the factors responsible for the increase (such as general growth in materials and construction costs) also applied to the cost of a reprocessing plant, reprocessing would continue to have a cost disadvantage.
- An increase in the extent to which waste from reprocessing can be stored more densely than unprocessed spent fuel (the densification factor) lowers the cost of reprocessing relative to direct disposal. However, reprocessing remains at a cost disadvantage under any plausible value for densification.

In conclusion, the cost of reprocessing may be comparable to that of direct disposal under limited circumstances, but under a wide variety of assumptions, reprocessing is more expensive (given current reactor technology).

Policymakers weighing the merits of reprocessing and direct disposal may have other concerns besides cost—such as extending U.S. uranium resources, reducing the threat of nuclear proliferation by adopting advanced burner technologies, or lessening the demand for long-term storage space. Judging whether those goals justify the added costs of reprocessing is ultimately a decision for policymakers.